US EPA Administrative Order on Consent
Article IV.G.3

2017 EGCS PH and Flowrate Report – Other Considerations

Part (1)

IV.G.3. 2017 EGCS pH and Flowrate Report – Other Considerations

"The 2017 EGCS pH and Flowrate Report shall include a section on other considerations. This section shall include:'

IV.G.3.a

"Exhaust Gas Composition – Provide a discussion in characteristics of exhaust emissions between using high sulfur fuel (with and without scrubbing) and low sulfur (0.1%) fuel."

Discussion: In comparing low sulfur fuel (MGO) to high sulfur fuel (HFO) and the effect of exhaust gas treatment by seawater scrubbing on exhaust components, SO_2, Particulate Matter (PM), particulate fractions PM_{10}, (sub 10 micron diameter), $PM_{2.5}$, (sub 2.5 micron diameter), particle number, Elemental Carbon (EC), and Organic Carbon (OC) will be the most dependent upon fuel sulfur content. CO_2, CO, and NOx emissions levels are similar between HFO and MGO, which indicates these parameters are independent from fuel sulfur content.

The use of an Exhaust Gas Cleaning system reduces the emissions of SO_2, PM, EC, OC, and visible smoke by using seawater to treat the exhaust gas, post combustion. Using seawater as a means of de-sulfurization has been used in land based applications for close to a century and its effectiveness in land applications is well proven. Water is one of the most efficient solvents found in nature and "seawater scrubbing" has a demonstrated positive impact on exhaust gas emissions over the broad range of operational conditions experienced onboard.

In addition to fuel sulfur content, the combustion efficiency and chemical composition of the fuel will also impact overall emissions. As HFO prior to combustion contains higher levels of metals, ashes, and sulfur than MGO, it could be concluded that MGO will produce less emissions than HFO if the emissions were based on content alone. However, due to differences in combustion efficiency a switch to low sulfur MGO versus HFO may not result in expected levels of emission improvement: diesel engine components are selected and timing is set in order to optimize efficiency and to limit emissions with HFO as fuel.

Combustion efficiency while operating on MGO is negatively impacted by the following:

- Improper Timing
- Low efficiency Injection components
- Incorrect injection viscosity
- Incorrect combustion Air/Fuel ratio

Carnival has committed to conducting a series of emissions studies, in cooperation with US EPA, on a number of ships equipped with Exhaust Gas Cleaning Systems (EGCS). The ships participating will represent all engine types currently active in the Carnival fleet. The goal of these studies is to expand the limited information available today regarding the relative emissions profile of the HFO/EGCS combination compared to MGO, as well as the contributions of "dry filters" (catalytic oxidation reactors) and other emissions reductions techniques used separately or in combination with EGCS.

Published peer-reviewed studies treating the topic of exhaust emissions reductions by seawater scrubbing are limited and show varying results, reflecting the inherent challenges in achieving accurate measurements in the post-EGCS operating environment.

The following summarizes findings from the limited number of published papers as well as two Carnival studies on ships with operational EGCS; the results indicate that operating with high sulfur fuel and EGCS is equivalent to low sulfur fuel and presents some evidence of exhaust emissions benefits over MGO.

SO2 emissions:

The removal of SO2 from exhaust via seawater scrubbing is a function of the buffering capacity of seawater and is dependent upon the dissolution of SO2 into seawater. The removal efficiency rate of SO2 by seawater scrubbing is well documented as greater than 90% and levels as high as 99% are consistently achievable.[4] Carnival's experience across 64 ships routinely operating EGCS is that exhaust SO2 emissions from ships operating high sulfur fuel in conjunction with Exhaust Gas Cleaning Systems are consistently lower than the mandated .1% sulfur content equivalent MGO. Typical values observed onboard Carnival Corp. ships during operation with HFO plus EGCS are the equivalent of .06% sulfur fuel, well below the required 0.1%S, and lower levels down to zero are considered easily achievable. Significant decreases of SO2 after the EGCS are well documented onboard and supported in literature with levels corresponding to the equivalent of fuel containing .03% S or less cited in a study by, Fridell 2014.[2]

Particulate Matter (PM) emissions:

Particulate matter is directly proportional to fuel sulfur content and influenced by engine load and other combustion efficiency factors. This correlation between fuel sulfur and particulate emissions is summarized in literature as an average of .33 g/kWh for MGO and 1.34 g/kWh for HFO. Particulate matter by mass reduction of 75% has been demonstrated in a study by Winnes and Fridell (2009), using EGCS as an abatement option with high sulfur fuel, the equivalent of switching from 2-3% S HFO to 0.1 S MGO.[1] Published values state a 25 to 98% reduction in PM emissions by mass may be realized by the use of EGCS. The variability in published PM values reflects the challenges associated with reliably measuring particulate after the EGCS, but there is general consensus that a shift to low sulfur fuel does not necessarily result in a reduction of the smallest diameter particles in comparison to high sulfur fuel. Instead, the limited data indicates that MGO contains a greater amount of submicron particles than HFO with EGCS.[1,2,5,6]

Tests conducted by Wartsila Technical Services onboard the M/V Crown Princess (with common rail engines) per ISO 8178 protocols demonstrated particulate emissions from HFO with a 2.32% S content in the range of 0 .81 g/kWh to 0.61 g/kWh prior to exhaust gas treatment by seawater scrubbing. Exhaust particulate measurements taken after the EGCS ranged from 0.28 g/kWh to 0.58 g/kWh, corresponding to a removal efficiency for particulate of 27 to 59% dependent upon test cycle, per ISO 8178 methodology.[5] Elemental Carbon and Organic Carbon exhaust emissions before and after exhaust gas treatment were evaluated and demonstrated a reduction of Organic Carbon ranging from 39 to 72% dependent upon load and a reduction in Elemental Carbon ranging from 19 to 42%.[5]

Table 1: Comparison of Particulate Emissions HFO and HFO+EGCS, Crown Princess

Parameter	HFO	HFO EGCS	HFO	HFO EGCS	HFO	HFO EGCS	HFO	HFO EGCS	Units
Engine Load	30	30	50	50	70	70	85	85	%
PM Quartz Filter	.61	.28	.68	.28	.76	.43	.81	.55	g/kWh
PM Teflon Filter	.66	.38	.69	.41	.76	.50	.79	.58	g/kWh
Organic Carbon	.16	.079	.10	.058	.074	.041	.053	.032	g/kWh
Elemental Carbon	.052	.04	.028	.023	.029	.019	.025	.014	g/kWh

A second series of tests on M/V Costa Fascinosa were conducted by Cetena S.p.a. following EN 13284 (consistent with EPA Method 5 combined with modified EPA method 202) at a typical DG port load of 58%.[6] The tests included a direct comparison of the emissions of MGO to HFO, MGO to HFO plus EGCS scrubbing, and HFO exhaust pre and post EGCS. Concentrations of particulate at the primary filters were 20% less for MGO than for untreated HFO exhaust, 17.75 mg/Nm^3, MGO versus 21.43 mg/Nm^3 , HFO. The reverse was documented at the secondary filters, MGO averaged particle mass of 49.71 mg/Nm^3 versus HFO with an average particle mass of 2.06 mg/Nm^3 a 96% greater mass of particulate for MGO. Comparing MGO to HFO plus EGCS a reduction in particulate mass of 74% HFO/EGCS over MGO was observed, 17.75 mg/Nm^3 for MGO and 4.63 mg/Nm^3 for HFO with EGCS. A similar result was observed at the secondary filters MGO emissions of 49.71 mg/Nm^3 and HFO with EGCS emissions of 11.15 mg/Nm^3 . In addition to total particulate mass, fractions of $PM_{2.5}$ and PM_{10} were assessed for MGO, HFO, and HFO plus EGCS. MGO PM_{10} at the primary filter of 1.76 mg/Nm^3 was 5% less than for HFO and HFO plus EGCS showed a 6% lower value than MGO at 1.66 mg/Nm^3. $PM_{2.5}$ values for HFO with untreated exhaust were higher than for MGO, a 227% increase. In contrast after exhaust gas treatment the levels of $PM_{2.5}$ in the treated HFO were 12% lower than MGO, 1.32 mg/Nm^3 and 1.16 mg/Nm.[3,6]

Table 2: Comparison of Particulate Emissions MGO, HFO, and HFO+EGCS, Costa Fascinosa

Parameter	MGO	HFO	HFO+EGCS	Unit
Particulate at Primary Filter	17.75	21.43	4.63	mg/Nm^3
Particulate at Secondary Filter	49.71	2.06	11.15	mg/Nm^3
PM_{10} Primary Filter	1.76	1.84	1.66	mg/Nm^3
$PM_{2.5}$ Primary Filter	1.32	4.31	1.16	mg/Nm^3

Reference:

1. Winnes, H., Fridell, E., 2009. Particle emissions from ships: dependence on fuel type. J. Air Waste Manage. Assoc. 59 (12), 1391–1398.
2. Fridell , E., Salo, K., 2014. Measurement of Abatement of Particle and Exhaust Gases in a Marine Scrubber. J. Engineering for the Maritime Environment 2016, Vol. 230 (I) 154-162.
3. Lack, D.A., Corbett, J.J., 2012. Black carbon from ships: a review of the effects of ship speed, fuel quality and exhaust gas scrubbing. Atmos. Chem. Phys. 12 (9), 3985–4000
4. Bluefield (2013), Evaluation of the Emissions Reduction Performance of a Hamworthy/Krystallon Exhaust Gas Cleaning Scrubber, Final Report MV APL England, May 2013
5. Wartsila, 2017. Emissions Measure Report Crown Princess.
6. Cazzola D., De Angelis, E., 2017. Cetena Report Costa Fascinosa Exhaust Gas Measurements.

IV.G.3.b

> **"Fuel Composition – In addition to sulfur content, provide Bunker Delivery Notes and any other information in Carnival's possession on the composition of the different fuels that Carnival uses, including the full range of metals, PAHs, and other pollutants."**

Bunker Delivery Notes (BDN) and laboratory analysis documents are provided separately in electronic form due to file size. The BDN are in two files: the Alaska ships that participated in "Ambient Monitoring" as referenced in section IV.2.D, and a number of the other Alaska ships that were not involved in Ambient Monitoring . Also provided is a summary data sheet of bunker events that also includes fuel composition, metals analysis, PAH and other parameters typically included in the BDN and associated laboratory analyses. The ships involved are the same as identified in section I.J of the AOC and that were operating in Alaska for the 2017 season.

Attachments:

1. Bunker Notes (BDN) Alaska Ships (Am.Monitor test group)
2. Bunker Notes (BDN) Alaska ships (others)
3. Summary sheet: Bunkers+Labs